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COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE- Efficacy of Dogleg Maneuvers in Improving Visibility in LM Descent

TM- 68-2013-2

DATE- June 25, 1968

FILING CASE NO(S)- 310

AUTHOR(S)- F. Heap

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ABSTRACT

The effect of dogleg maneuvers (azimuth turns) on the visibility in the touchdown area during LM descent was studied. A turn procedure was developed in which the flight profile (altitude vs. range) was essentially unchanged from the no-dogleg approach. In this way, the azimuth effects were separated and a systematic evaluation of maneuver starting times and azimuth angles could then be made.

Visibility criteria were examined and a criterion developed which required that craters subtending half a degree at the commander's eye should be visible during the last 100 seconds of approach prior to losing sight of the touchdown spot as it disappears beneath the LM. Conditions under which such craters could be detected, as a function of the scene contrast and taking into account field conditions, were established.

Under the assumptions of the study, the conclusions are that a dogleg maneuver could provide a better utilization of the maneuvering ΔV for sun angles at the high end of the 7-20 degree range. For the low end of the range, however, the dogleg has no advantage.

A strategy was postulated and examined in which the results of the study were applied to a landing at 20 degrees sun angle. The results suggest that 25 feet/second of the descent ΔV budget Final Approach phase maneuvering allowance should be earmarked for a 17-20 degree dogleg at sun angles near 20 degrees.

It is recommended that the Apollo Flight Mission Assignments document be changed to reflect these results.

(NASA-CR-96104) EFFICACY OF DOGLEG MANEUVERS IN IMPROVING VISIBILITY IN LM DESCENT (Bellcomm, Inc.) 29 p

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BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Efficacy of Dogleg Maneuvers in Improving Visibility in LM Descent
Case 310

DATE: June 25, 1968

FROM: F. Heap

TM-68-2013-2

TECHNICAL MEMORANDUM

1.0 INTRODUCTION

Visibility of the touchdown area is required during the final approach and landing phases (Phases II and III) of LM descent for lunar surface evaluation and touchdown spot selection by the crew. The currently accepted range of sun elevations for the first manned lunar landing is 7 to 20 degrees above the horizon, with the approach down sun. The azimuth angle between the LM descent ground track (in the plane of the CSM orbit) and the sun direction is variable, depending on the landing site latitude and longitude and the date of landing, but it will normally be less than 7 degrees for landing sites in the Apollo zone of interest. It has been indicated (References 1 and 2) that, with such small azimuth angles between sun line and LM track, visibility in the nominal touchdown area is poor (see later discussion for interpretation of visibility requirements) for sun angles at the upper end of the 7 to 20 degree interval, until the range to nominal touchdown is only 1000 to 1500 feet, or about 40 seconds before the touchdown spot passes out of view beneath the LM.

The purpose of this study is to investigate the effect on visibility of performing a dogleg (azimuth turn) maneuver during the final approach or landing phases of the LM descent. The increase in the time interval during which scene contrast exceeds certain criteria of acceptability is determined as a function of increase in ΔV cost, for various dogleg angles and maneuver starting times. Sun angles in and above the 7 to 20 degree range are considered.

2.0 THE DOGLEG MANEUVER

The dogleg maneuver trajectories were calculated by using the Bellcomm Apollo Simulation Program (BCMASP)(including recent modifications, see Reference 3) with a modified LM descent guidance subroutine (GUIDL2). In the simulation, the maneuver is initiated at a given time (t_b) after Hi Gate.

Starting at this time, and continuously thereafter, the aim point's downrange and crossrange components are changed so that, with respect to the LM's current position (P), the aim point (A) is always at the desired dogleg angle (ψ) from the original LM track direction, (Figure 1). In this way, the flight direction is made to converge to the desired dogleg direction. The distance of the aim point from the current position is adjusted so that the total range in the phase (RGOI) is maintained essentially constant. (In the program, the increment of range gone in a particular integration cycle (ΔRGONE) is approximated by the chord between two consecutive positions of the LM, as shown). The object in keeping the range constant is to keep the trajectory profile essentially similar to that with no dogleg. In this way, the time histories of the pitch angle, the flight path angle and look depression angle (see Figure 2) should be essentially unchanged from the no dogleg case. Thus, visibility effects due to changes in look depression angle are eliminated.

The guidance mechanization is essentially that of Reference 4. Three differences should be noted, however. First, the change in the aim point in toto at the start of the maneuver and each subsequent integration is not consistent with the pilot-performed landing point redesignation procedure of Reference 3, in which the landing point position is altered by small increments of the sighting angles in the LM body axis system. This is not an important factor, however; piece-meal alteration of the aim point to effect the dogleg would not significantly affect the results. The purpose here is to compare different dogleg angles and maneuver starting times so it is sufficient to employ the simpler mode.

The second, related point is that the LM PNGCS is not currently mechanized to perform a dogleg maneuver as simulated here. The simulation was arranged this way so that a systematic, parametric evaluation of the dogleg could be made. The dogleg as performed here could be approximated by a short series of redesignations if it were not incorporated as an automatic PNGCS feature.

Thirdly, the guidance feature of Reference 4, which displays the current landing point to the pilot by aligning the vertical reticle of the landing point designator (LPD) on it and indicating its elevation angle, would be of no value during the turn in the early stages of the maneuver as performed here. The interim touchdown points are artifices and the actual touchdown point is not determinable until the turn is complete and the flight azimuth is equal to the dogleg azimuth. A reasonable display during the turning period would be provided by yawing the vehicle about the thrust axis to place the vertical reticle of the LPD (that is, the LM XZ body plane) on the tangent to the instantaneous flight path. In this way, the LM commander could evaluate the visibility in the tangent plane and "ease out of the turn" when he judged the visibility to be adequate, even if the programmed dogleg azimuth had not yet been achieved.

3.0 VISIBILITY CRITERIA

Much has been written on what is considered acceptable visibility, how to measure it and how to decide whether it is present on the moon with various sun elevation angles, look angles, lunar features, etc. Reference 5, a fairly detailed summary of most of the published analytical studies on lunar surface visibility, illustrates the subjectivity of the establishment of criteria.

In a more recent study (Reference 6), it was suggested that the crew should be able to detect a 20 foot diameter crater with 10:1 diameter to depth ratio at an altitude of 3000 feet, that is, at about 10,000 feet range. This is a subtended angle at the eye of 0.115 degrees. Considering that the accuracy of the LPD is likely to be 1/2 to 1 degree and that the minimum cross-range redesignation discrete is 2 degrees, this criterion appears to be highly conservative. The situation is illustrated in Figure 3.*

The detectability criterion used in Reference 6 required that the bright side and either the geometric or photometric shadow in the crater should be individually detectable. In the visibility computation, correction factors were applied to correct the composite calculated contrast to agree with field conditions, that is those expected to be applicable to the lunar landing task. These result in the final data being applicable to a 99% probability that a crater is detectable (with a yes-no judgment as opposed to a temporal forced-choice judgment**) in a short glimpse (0.33 seconds). While it is likely that this

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*The subtended angles of Figure 3 are represented correctly when the page is held at arms-length (28" from the eye).

**In the temporal forced-choice experiment, the observer chooses from four time intervals the one in which a visibility target appears. A target always appears in one interval and he is not allowed to make no-choice. In the yes-no experiment, the observer states whether or not he sees the target in a single time interval. A target may or may not be shown in any interval. The procedure is explained fully in Reference 7.

kind of criterion is applicable in the last 30 seconds prior to the landing site passing out of view beneath the LM, when the actual touchdown spot is being selected, for most of the final approach phase it is probable that a "rejection" process rather than "selection" will be used and a much less stringent criterion is necessary. To reiterate, it is unlikely that it would be necessary to be able to say with 99% probability after a short glimpse that there was not a 20 foot crater (2 feet deep) at the touchdown spot while still almost 2 miles from touchdown.

Looking at Figure 3 again, it would seem more reasonable that 1/2 degree craters are those of interest. In the landing phase,* the two feet deep 20 ft. diameter craters (the limiting hazard) would subtend 1/2 degree at 2300 feet (approximately 2/5 n. mi.) range. In the nominal trajectory, the time to go to loss of visibility at this point is 45 seconds, enough time for selection of a hazard-free spot and manual steering to it. In the final approach phase, again considering the LPD accuracy and the minimum cross range discrete of 2 degrees, half-degree craters would appear to be the minimum size of interest.

In addition, it is unlikely to be necessary that the probability of detection of a crater subtending half a degree at any point should be constant during the whole final approach and landing. In the landing phase, detectability should be such as to ensure high probability of detecting the hazards in a searching (quick glimpse) operation. The LM commander is at this point performing the task of picking a landing spot from an accessible field - a positive function. In the final approach phase, however, the operation is the opposite - not a search for one spot, but a rejection of the current landing point if it appears unsatisfactory. This requires a different technique - a concentration on the area indexed by the LPD and only an indication (not necessarily an almost certainty) that that area is unsafe. The different technique is required because a decision to act would be postponed, due to the uncertainty of the LPD indication and the 2 degree minimum redesignation, until the commander was almost certain that the hazard did indeed exist at the indicated landing site and was about one degree across.

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*It is convenient to examine separately the visibility requirements in the final approach and landing phases. From the guidance viewpoint, they are considered as one; operationally, there is no clear break between them. The point at which the commander takes over manual control of the LM, which of course is not fixed, is normally considered to be the start of the landing phase. For the purposes of this report, the landing phase is considered to commence at an altitude of 750 feet, about 2300 feet range and 85 seconds to go to nominal touchdown.

However, to retain a measure of conservatism, the yes-no judgment, quick-glimpse, 99% probability criterion is retained for both the final approach and landing phases in the following development of a measure of required visibility. The difference from Reference 6 criteria, then, is that 1/2 degree is adopted as the size of craters of interest, for reasons explained above.

4.0 DETECTABILITY CRITERION USED IN THIS REPORT

Contrast is defined in Reference 1 as

$$C = \frac{1}{\phi} \cdot \frac{\partial \phi}{\partial \tau} \cdot \Delta\tau$$

where ϕ is the Willingham 1963 photometric function and τ is the luminance longitude. In the brightness range of interest (75 to 800 foot-lamberts), the liminal contrast for objects subtending 1/2 degree, from the standard Tiffany data, is .003. This data has to be corrected for three factors, as shown in Reference 7. To convert from the 50% probability of detection to 99%, the liminal contrast has to be multiplied by a field factor of 2. A further field factor of 2 is applicable to convert from unlimited scan time to a 0.33 second short glimpse and a third field factor of 2 converts from the temporal forced-choice method to a yes-no judgment. These factors have been conservatively combined to give a value of 10, resulting in a contrast criterion of 0.03.* That is, if the calculated contrast is 0.03, there is a 99% probability that a contrast-producing feature subtending half a degree will be unequivocally detectable in a short glimpse. The effects of choosing a value other than 0.03 as a criterion are discussed in a later paragraph.

To calculate the contrast, a crater is approximated by a surface element, with a slope difference of 10 degrees from the surrounding background. (The lip angle of a 10:1 circular crater is 22-1/2 degrees; the mean slope of the crater wall visible during the final approach is close to 10 degrees.) It was assumed that the circular target data was applicable to the elliptic target presented by a crater having the same lateral angle subtended at the eye.

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*Ziedman, in Reference 6, used a field factor of 4 to convert Taylor data to field conditions, as the Taylor data is already applicable to short glimpses. Applying the Taylor data to determine the required contrast for a 0.115 degree crater gives 0.018. The contrast required to detect a 0.115 degree crater in field conditions by Ziedman's criterion would therefore be 0.07 (4 x 0.018).

5.0 STUDY LIMITATIONS

Two points have not been considered in this study

1. It has been assumed that the sun azimuth with respect to the LM track prior to the dogleg is zero. This is only true for a small number of cases. The angle depends on the date of the landing; it is usually less than 7 degrees, for sites in the Apollo zone of interest.

   If there are no other factors favoring a turn either to the left or the right, then the dogleg should be made to increase the existing azimuth. The results will be similar to those of this study. If, because the commander's view is predominantly of terrain to the left, a turn to the left is considered mandatory, then about half the dogleg angles would have to be increased by twice the original sun azimuth to approximate the visibility results of this study. In this latter case, it would intuitively seem uneconomical to do a dogleg to the left if the LM track was already 5° or more to the right of the sun line. Further analysis in this area is required to establish a mission rule.

2. No consideration is given to pilot redesignation for obstacle avoidance and touchdown point selection. These are, as in the case of no dogleg maneuver, arbitrary perturbations superimposed on the basic trajectory. If the visibility is sufficient to give adequate confidence in the results of such action, then the need for continuation of the dogleg is diminished or removed. Due heed must be taken of the flight path elevation and azimuth that will result from such a redesignation, however; if the angle between the sun and the flight path tends to decrease as a result of such redesignation, a progressive worsening of the visibility can be expected. The general rule in such a situation would be to redesignate into regions where the visibility is better than that at the current site. The flight path curvature resulting from the redesignation will then cause the visibility to further improve.

6.0 DISCUSSION OF THE RESULTS

Calculations of 28 dogleg trajectories were made for dogleg angles of 5, 10, 15, 20, 30, 40 and 50 degrees, with the maneuver staring at 20, 40, 60 and 80 seconds after Hi Gate (defined as the start of the transition to the Final Approach phase).

Figure 2 is an illustration of the terms used in the presentation of the data. Figure 4 (a through h) shows the results of the trajectory calculations for a no dogleg approach (based on the Reference 8 trajectory) and for a sample dogleg of 20 degrees started 20 seconds after Hi Gate, illustrating that the flight profile variables (altitude, flight path angle, look depression angle) are essentially unchanged in the dogleg.

Contrast time histories for no dogleg and the four 20-degree dogleg approaches for sun elevation angles of 7, 13.5, 20, 25 and 30 degrees are shown in Figure 5.*

The time intervals in which the contrast is greater than 0.03 are given in Table I. The interval ends at the point where the touchdown spot passes out of sight beneath the LM. The total powered descent ΔV and the increment in ΔV above the no dogleg run are also given. These data are plotted in Figures 6, 7 and 8 as described below.

For sun elevation angle 7 degrees, the contrast is so great without a dogleg that none need be considered. The data shows (and Figure 5 illustrates) that there is a decrease in contrast during the dogleg.

For sun elevation angle 13.5 degrees, a dogleg decreases the contrast generally and is therefore also disadvantageous.

With 20 degrees sun elevation angle, all of the doglegs except for those with 5 degrees azimuth increased the contrast in the final approach phase. Figure 6 illustrates the increase in the time interval between attaining a contrast level of 0.03 and loss of visibility of the touchdown spot, as a function of the incremental ΔV required to perform the dogleg. Dogleg angles less than about 6 degrees cause a decrease in visibility time. The greatest rate of increase in perception time occurs between 6 and about 18 degrees, with diminishing returns thereafter. In this range, a delayed start gives more time for a given ΔV but the time gain may not be adequate, as explained later. At greater angles, the dogleg should be started early, for best effectiveness. The line labelled "Hover time cost" shows the ΔV cost of hovering (or, equivalently, changing the landing site in the landing phase while traveling at low horizontal speeds). Obviously a tradeoff exists between two strategies: employing ΔV to get a better view

*The contrast shown is that at the "actual touchdown point", not at the "nominal touchdown point". Hence, for dogleg approaches, the contrast is different from the no dogleg approach even before the dogleg commences.

of the terrain fairly early in the final approach by doing a dogleg; and using it when the contrast is higher during the landing phase to put the final touches to an otherwise blind approach.

The following paragraphs suggest a strategy for utilization of the better cost effectiveness shown by the dogleg at 20 degree sun elevation angle in the context of landing in an Apollo site.

It is assumed, a priori, that half-degree craters should be visible at 100 seconds prior to loss of sight of the touchdown spot. At this point, the LM will be at an altitude of 4,000 feet, about 14,000 feet uprange from landing. At this range, a half-degree crater is 125 feet across. Conservatively allowing 15 seconds before a redesignation is made, by which time the altitude will be 3,000 feet, the largest single crater in any of the Apollo landing sites (1,500 feet diameter) could be easily avoided with a three-pulse (6°) cross-or up/down-range redesignation (approximately 1,000 feet) at a maximum ΔV cost of about 25 feet/second, and a highly probable cost of very much less by going crossrange (Figure 6 of Reference 9). This value is conservative, because it is assumed naively that the commander allows the LM to be steered toward the crater by the dogleg guidance even though a crater of such a size will be visible at the estimated end-of-dogleg landing point long before the 100 second point.

After such a redesignation to clear the obstacle at the end of the dogleg trajectory, the maximum size of subsequent redesignation should be single-pulse, as each half-degree crater is avoided as it comes into view. (The visible crater size will, in fact, be decreasing continuously as the contrast increases due to increasing look depression angle, so long as the azimuth angle is not decreased or the trajectory stretched down-track by redesignation.)

One hundred seconds of visibility can be bought with 25 feet per second of ΔV by performing, say, a 17-degree dogleg commencing at 20 seconds after Hi Gate. Using such a strategy, 25 feet per second out of the 60 feet per second ΔV allowance allocated in the descent ΔV budget for final approach phase maneuvering should be made available for the dogleg maneuver for high sun angles (approaching 20°). In this way, maximum utilization of the maneuvering allowance will be effected.

It should be noted that the contrast level at loss of visibility is the same, with or without a dogleg, for a given sun angle. The reason for this is that at large look depression angles, the effect of look azimuth angle is insignificant.

Results similar to those for 20 degree sun angle are shown in Figures 7 and 8 for 25 and 30 degree sun angles. While other considerations (LM heating on the surface, landmark sighting, etc.) might otherwise preclude the use of these higher sun angles for early missions, flight experience might allow using the advantages in launch opportunity to be gained from increasing the sun angle range above 20 degrees.

It was stated previously that the establishment of visibility criteria is highly subjective. In this context, it is wise to examine the sensitivity of the results to the criterion chosen. For instance, Figure 5 results show that if a constrast of 0.02 is the level of acceptability, adequate visibility exists for 20 degree sun angle for all the final approach for most doglegs; if a contrast of 0.04 is necessary, then the dogleg has no worthwhile advantage.

7.0 EXTENT OF THE WASHOUT REGION

Reference 10 states as a requirement that there shall be a difference of four degrees between the sun elevation angle and the viewing angle (look depression angle) in the visibility phases of LM descent if the azimuth difference is zero. The point is illustrated in Reference 11 with a Lunar Orbiter V oblique photograph, in which the washout region extends four degrees below the shadow point, for a sun elevation angle of 22 degrees.

The contrast is good (about 0.3) at the beginning of the Final Approach phase (Figure 5(a)) for 13.5 degree sun elevation angles, even though the difference between sun angle and look depression angle (Figure 4(e)) is only 2.5 degrees. Figure 9 shows contrast versus look depression angle for five sun angles from 13.5 through 22 degrees and illustrates that the contrast at a look angle four degrees from the sun angle increases as the sun angle decreases. At the lower sun elevation angles, less than four degrees difference between the sun elevation angle and the look depression angle is necessary for good visibility.

8.0 CONCLUSIONS

An analytical study to determine the effectiveness of dogleg maneuvers to enhance visibility during LM approach to landing has been made. The following limitations and assumptions in the study are reiterated.

1. A particular guidance scheme was formulated to effect the dogleg maneuver which differs from the LM guidance mechanization of Reference 4. In particular, piecemeal alteration of the landing point was not used; in addition, LPD operation would differ.

2. Contrast for 10 degree slope change, based on Willingham 1963 photometric function, was used as a measure of visibility. Field factors were applied so that the calculated data applies to 99% probability, short glimpse, yes-no judgment that a half-degree or larger object could be detected. The 10 degree slope was assumed to reasonably represent the visible portion of a 10:1 diameter to depth circular crater.

3. It was assumed that the sun azimuth with respect to the LM track prior to the dogleg was zero. In general this will not be so. If it is permissible to turn the LM in either direction during the approach, prior sun azimuth will be advantageous; if turns to the right are prohibited, prior sun azimuth with the sun's rays to the left of the LM track will be a disadvantage.

4. No consideration was given in the analysis to the effects of pilot redesignation of the landing point. An empirical rule of thumb for increasing visibility in redesignations was suggested, however.

The conclusions are:

1. The dogleg maneuver is detrimental if the sun elevation is in the lower half of the 7-20 degree range.

2. At 20 degree sun elevation, a dogleg maneuver can provide extra time for evaluation of half-degree craters and will prevent the washout region from enveloping the landing point, but will not increase the contrast level at the point when the touchdown spot disappears beneath the LM window bottom prior to touchdown.

3. Above 20 degrees sun angle, the dogleg maneuver would eliminate the washout region passing over the landing spot. It could provide reasonable site evaluation times at little ΔV cost; if other constraints limiting the sun angle range to 20 degrees were found to be over-strict, it is possible that sun elevations greater than 20 degrees could be used for later lunar landing missions, with relaxed launch opportunity constraints.

4. The dogleg maneuver should be started soon after Hi Gate to provide an adequate increase in evaluation time for the least ΔV; the incremental advantage decreases as the dogleg angle increases

above about 18 degrees. The ΔV needed to reach very large angles could probably be turned to greater advantage by providing increased hover time.

5. It is recommended that further studies be made to resolve the question of adequate visibility criteria, in view of the need to maintain a reasonable lighting window. In advance of such a resolution, it is suggested that 25 ft/second of the descent ΔV budget Final Approach phase maneuvering allowance be earmarked for a 17-degree dogleg at high sun angles.

6. It is recommended that the Reference 10 requirement quoted above should be reworded to reflect the findings of this memorandum.

2013-FH-wcs

F. Heap

Attachments
  Table I
  References
  Figures 1-8

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9. Landing Point Designation Procedures and Capability, J. D. Montgomery and R. H. Lefler, MSC Internal Note 67-EG-24. August 1967.

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TABLE I - TIME INTERVAL PRIOR TO LOSS OF VISIBILITY (44 SECONDS FROM TOUCHDOWN) DURING WHICH THE CONTRAST FOR 10 DEGREE SLOPE CHANGE EXCEEDS 0.030

DOGLEG ANGLE (DEGREES)	TIME OF BEGINNING DOGLEG (SECS)	TIME INTERVAL (SECONDS) FOR C>0.030 FOR SUN ANGLES THUS:					POWERED DESCENT ΔV (FT/SEC)	INCREMENTAL ΔV (FT/SEC)
		7°	13.5°	20°	25°	30°		
NO DOGLEG		A	A	26	14	9	6600	0
5	20	A	A	23	15	11	6606	6
5	40			23	15	10	6604	4
5	60			22	15	10	6603	3
5	80			22	15	11	6602	2
10	20	A	A	44	16	14	6613	13
10	40			42	16	14	6610	10
10	60			40	16	14	6608	8
10	80			38	16	14	6607	7
15	20	A	A	76	27	18	6620	20
15	40			70	26	17	6616	16
15	60			62	26	17	6612	12
15	80			55	27	18	6610	10
20	20	A	A	109	49	22	6631	31
20	40			97	42	20	6624	24
20	60			81	36	19	6618	18
20	80			26	34	20	6614	14
30	20	A	A	136	78	29	6671	71
30	40			119	63	25	6652	52
30	60			101	52	24	6638	38
30	80			80	48	25	6628	28
40	20	A	A	155	105	40	6715	115
40	40			136	84	34	6682	82
40	60			115	73	32	6658	58
40	80			91	70	33	6643	43
50	20	A	A	A	129	94	6758	158
50	40			148	108	74	6704	104
50	60			126	96	56	6681	81
50	80			102	90	42	6660	60

A ~ ALL OF FINAL APPROACH PHASE.

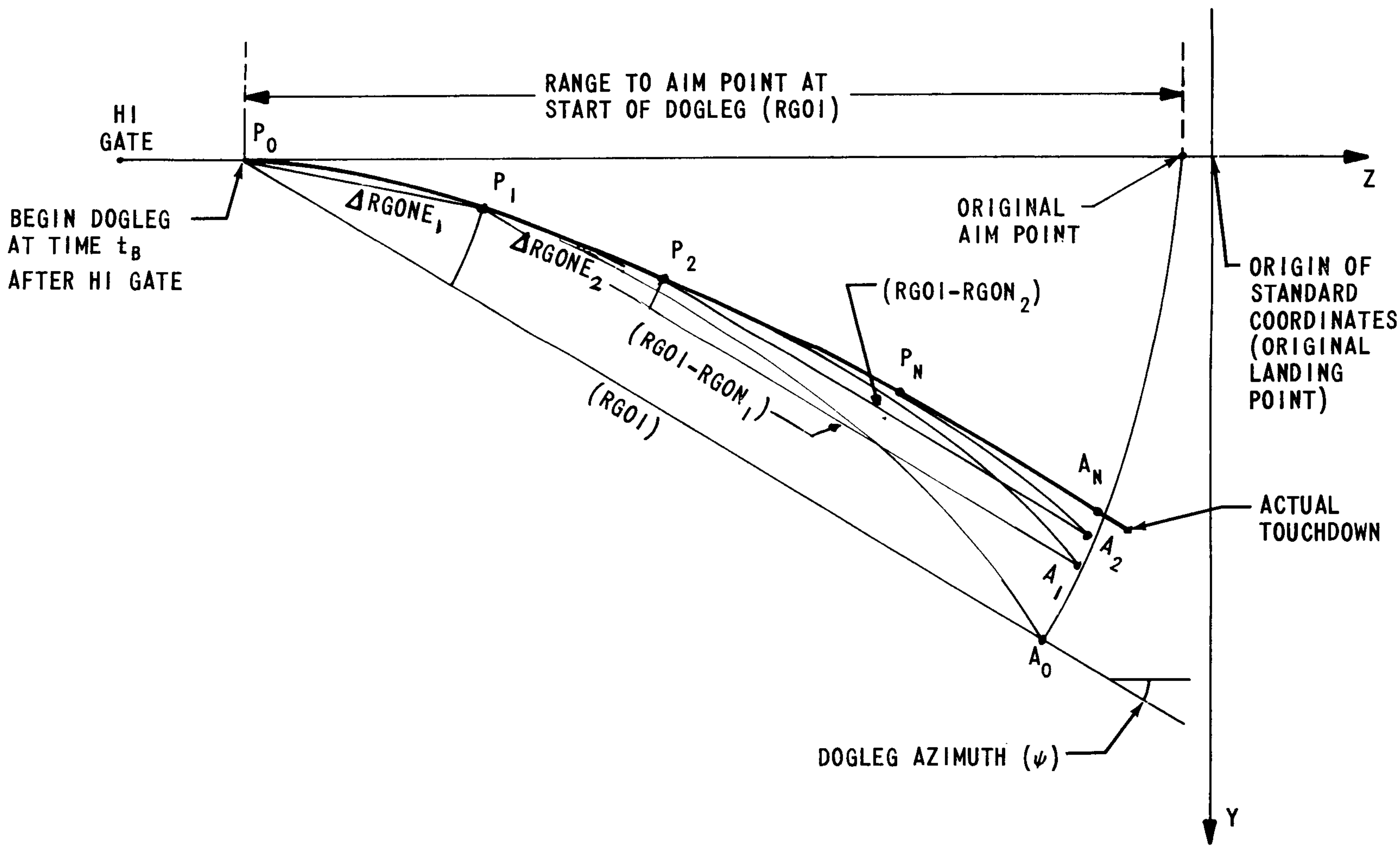


FIGURE I - PLAN VIEW OF DOGLEG MANEUVER

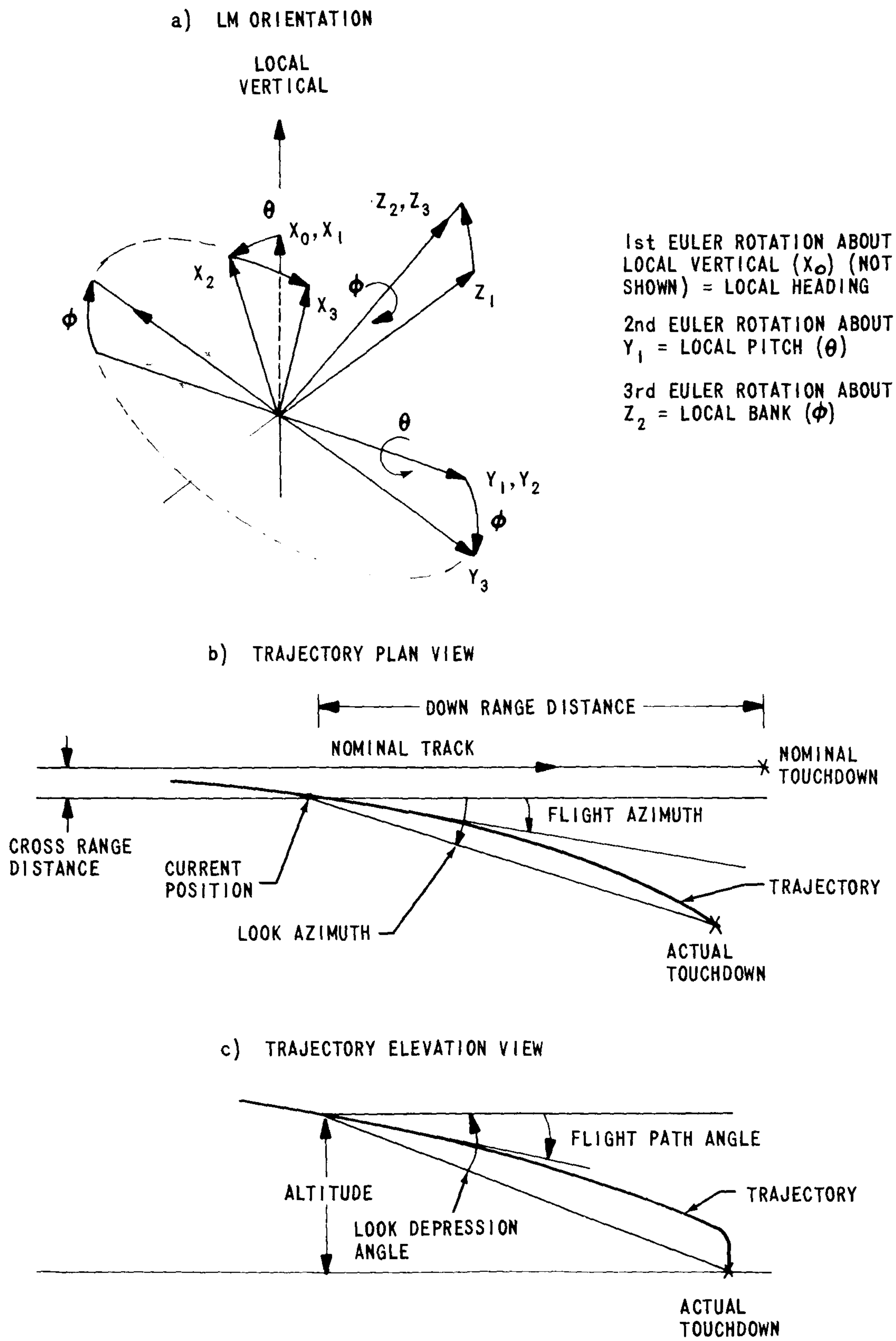


FIGURE 2 - EXPLANATION OF TERMS

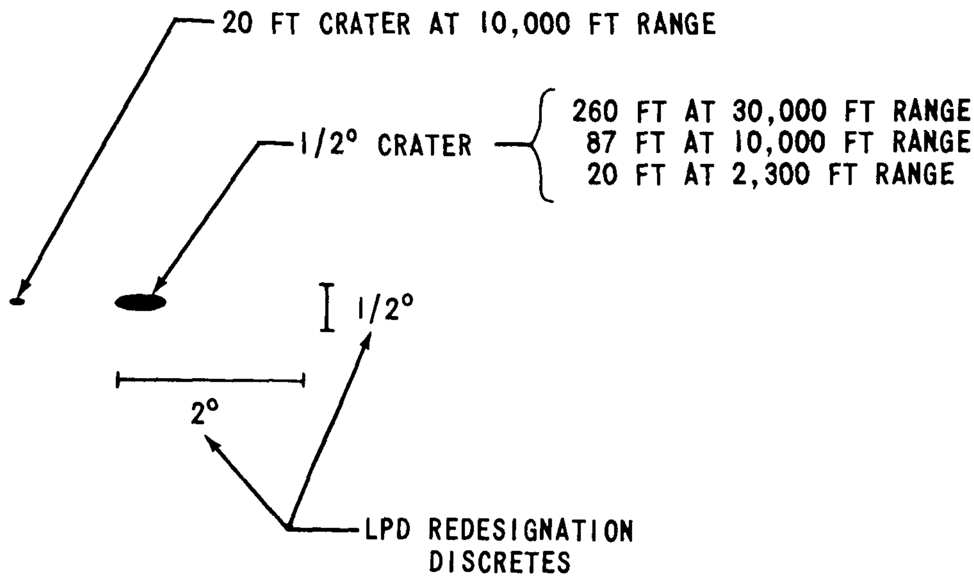
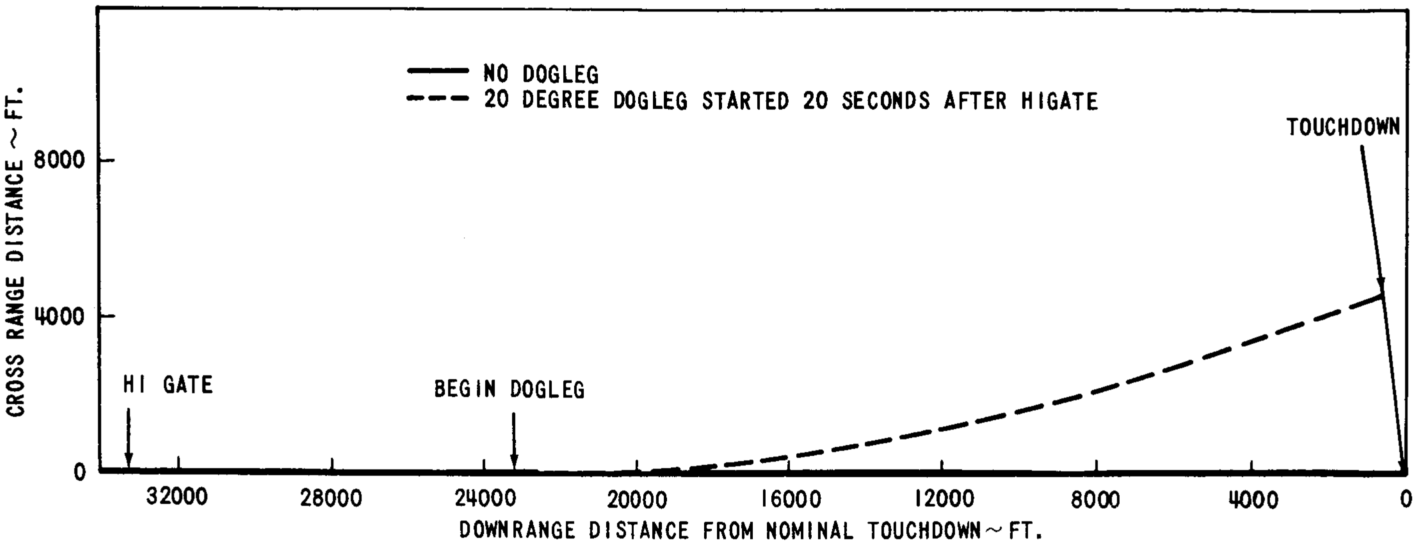
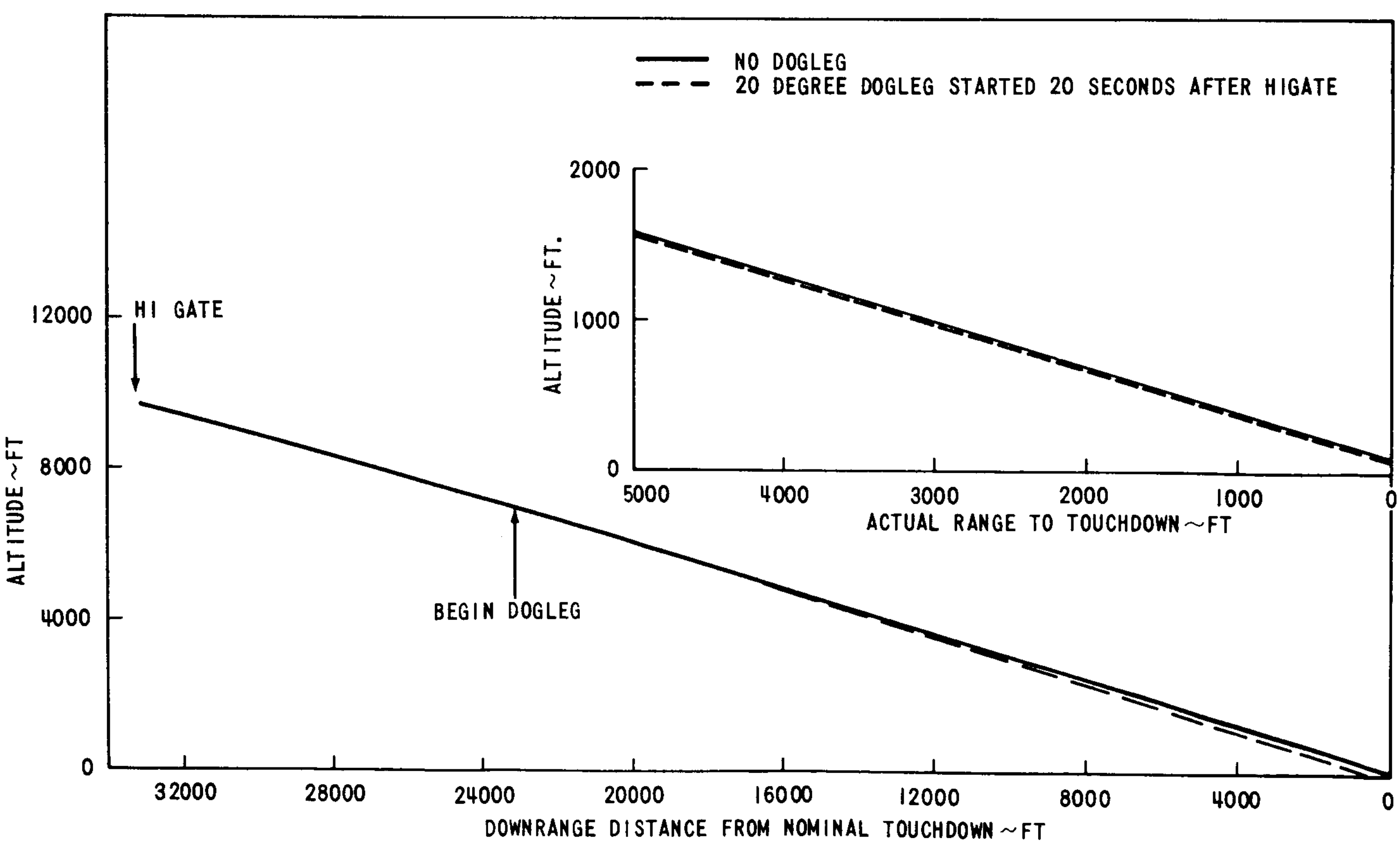


FIGURE 3 - RELATIVE SIZE OF LPD GRID AND REPRESENTATIVE CRATERS

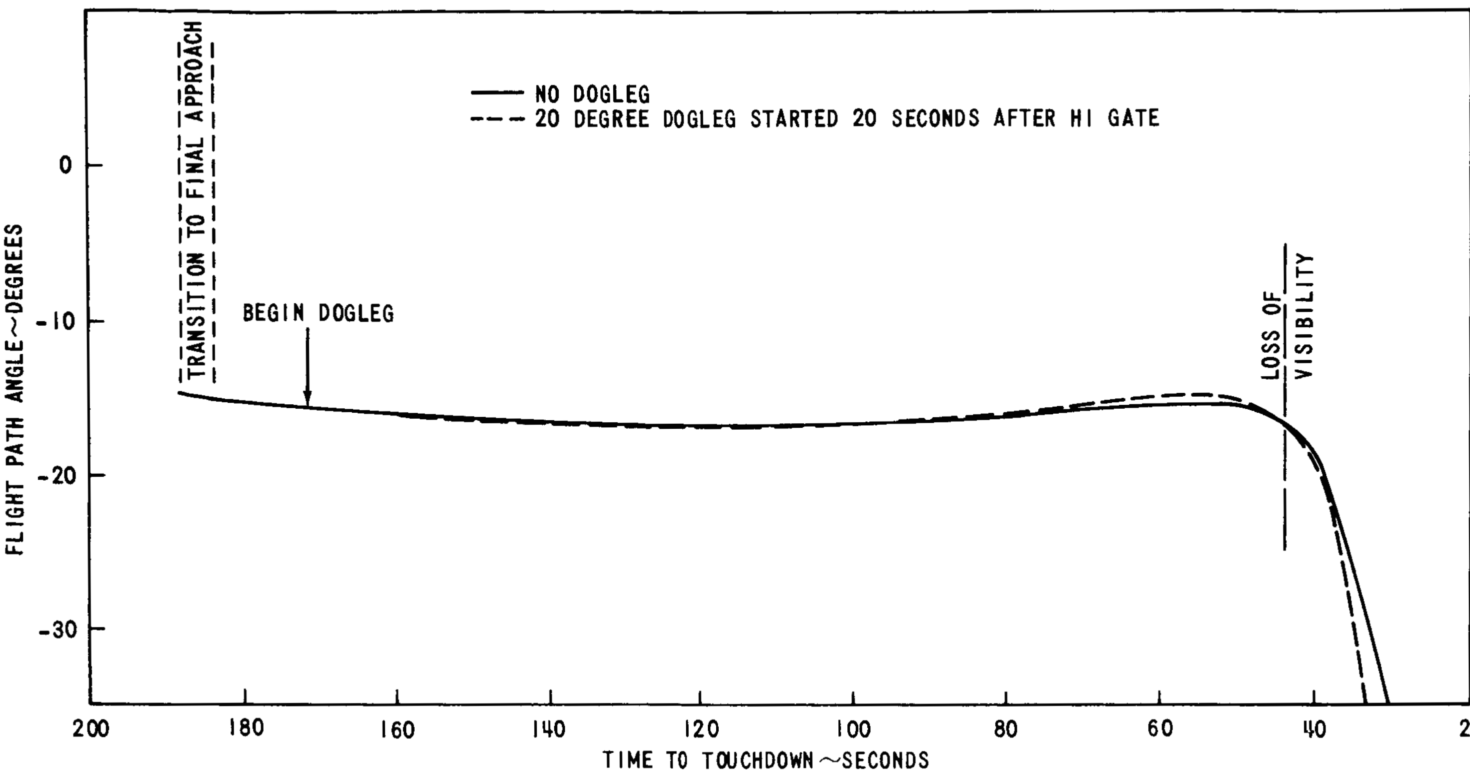


a) CROSS RANGE DISTANCE

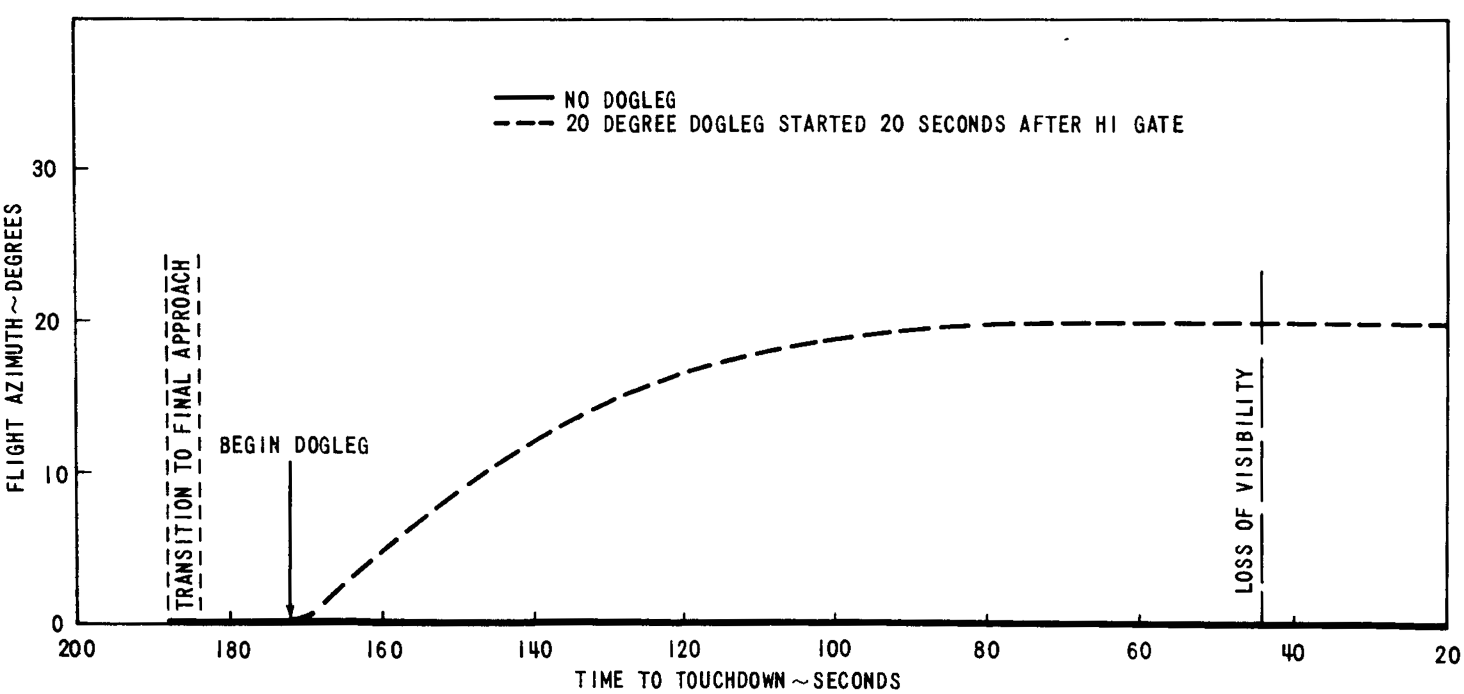


b) ALTITUDE

FIGURE 4 - COMPARISON OF DOGLEG AND NO DOGLEG APPROACHES

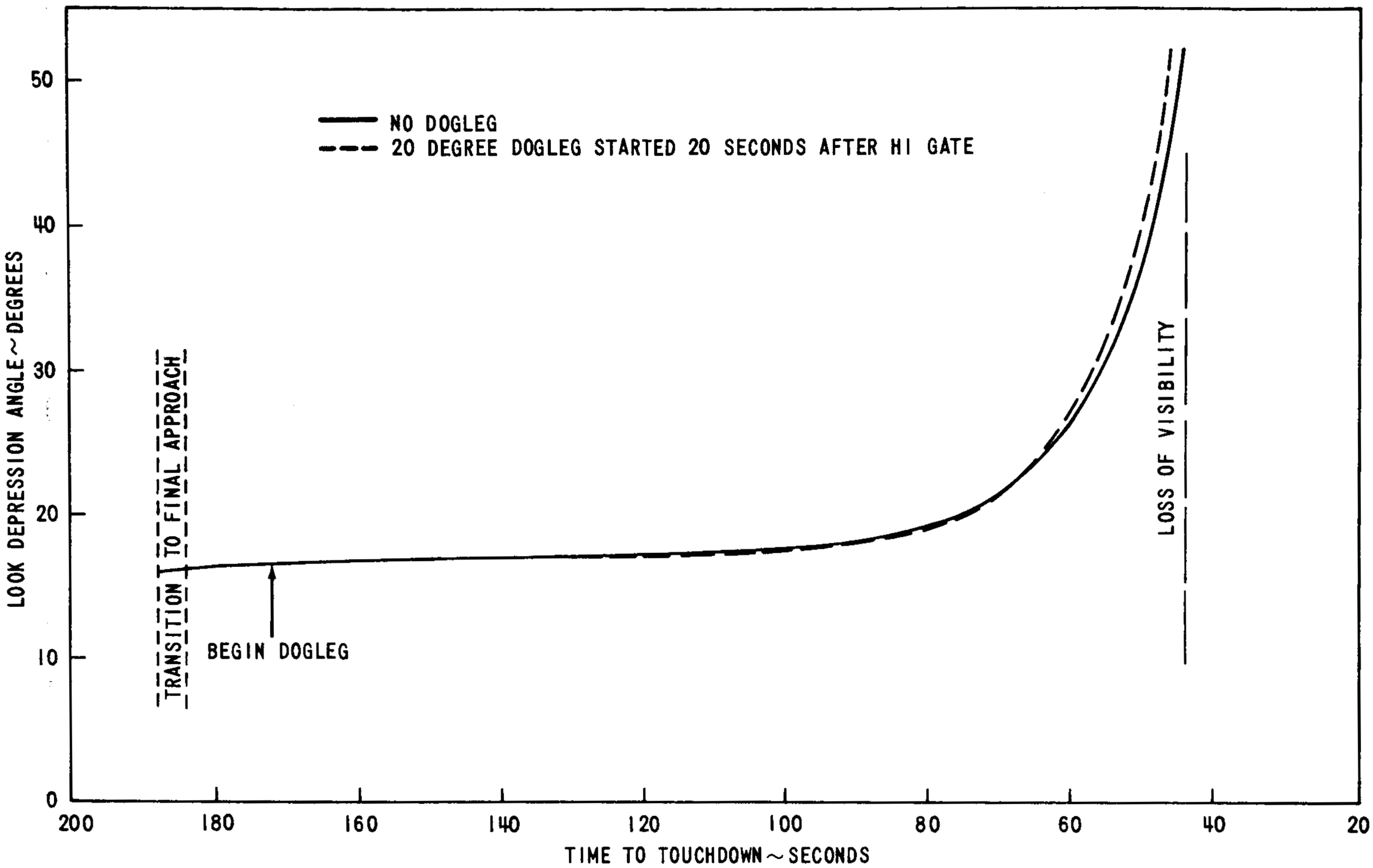


c) FLIGHT PATH ANGLE

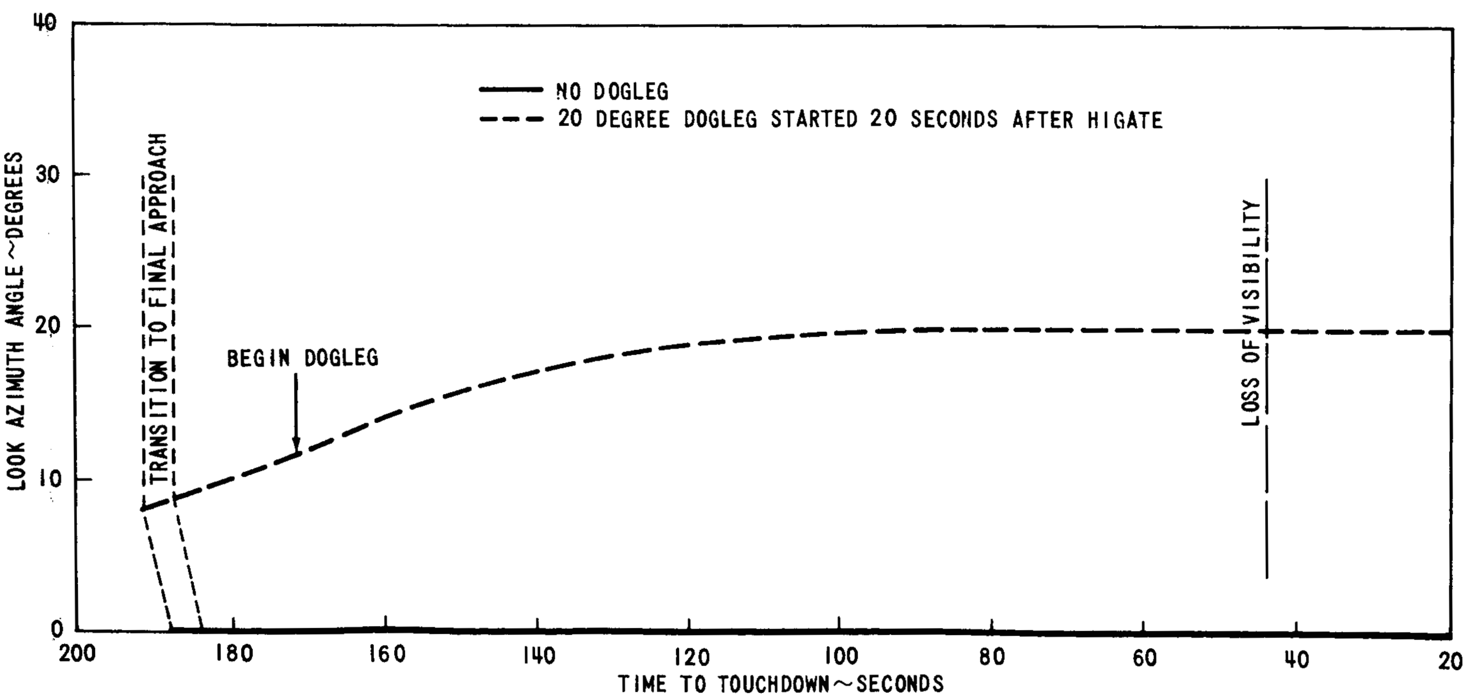


d) FLIGHT AZIMUTH ANGLE

FIGURE 4 - COMPARISON OF DOGLEG AND NO DOGLEG APPROACHES (CONT.)

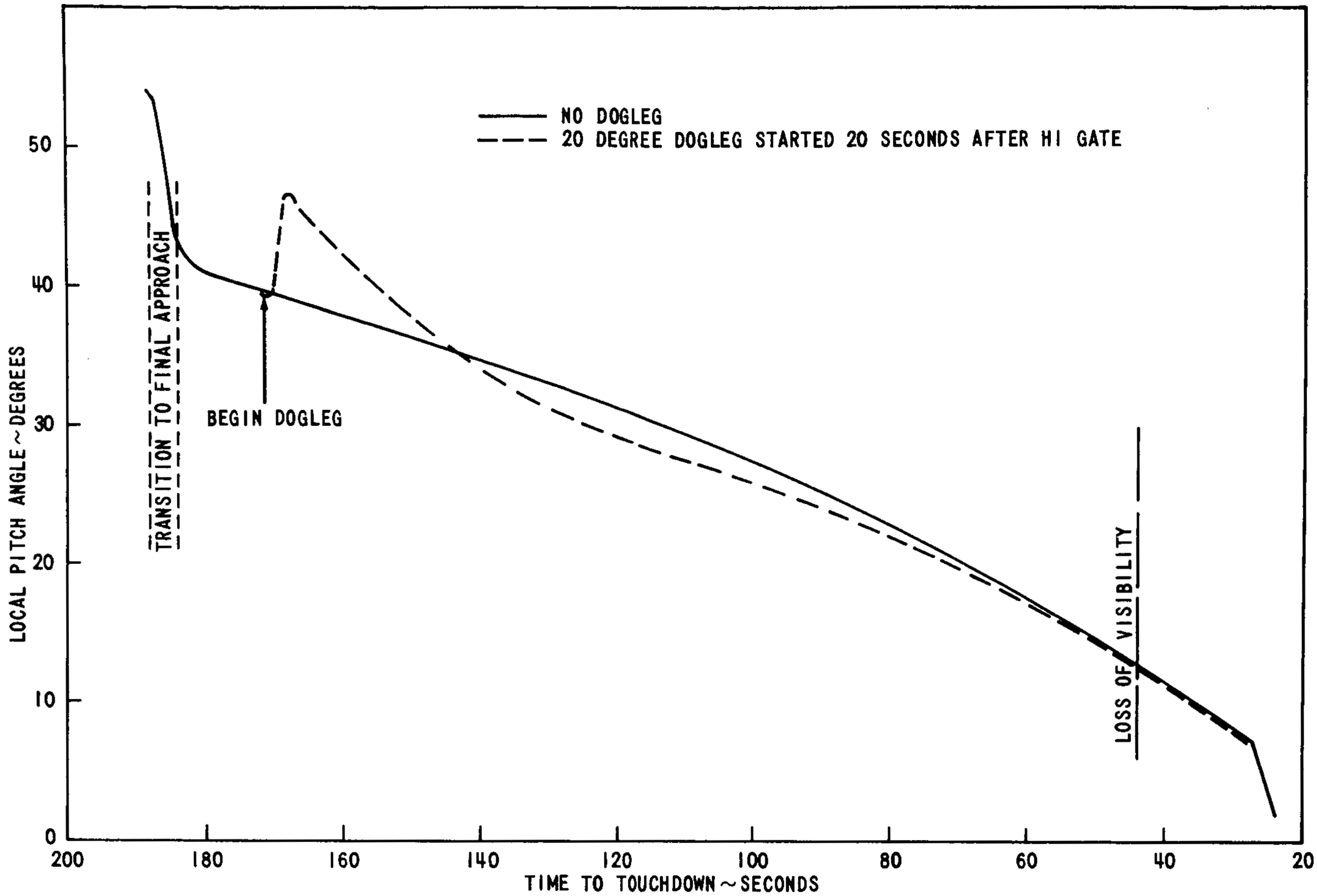


e) LOOK DEPRESSION ANGLE

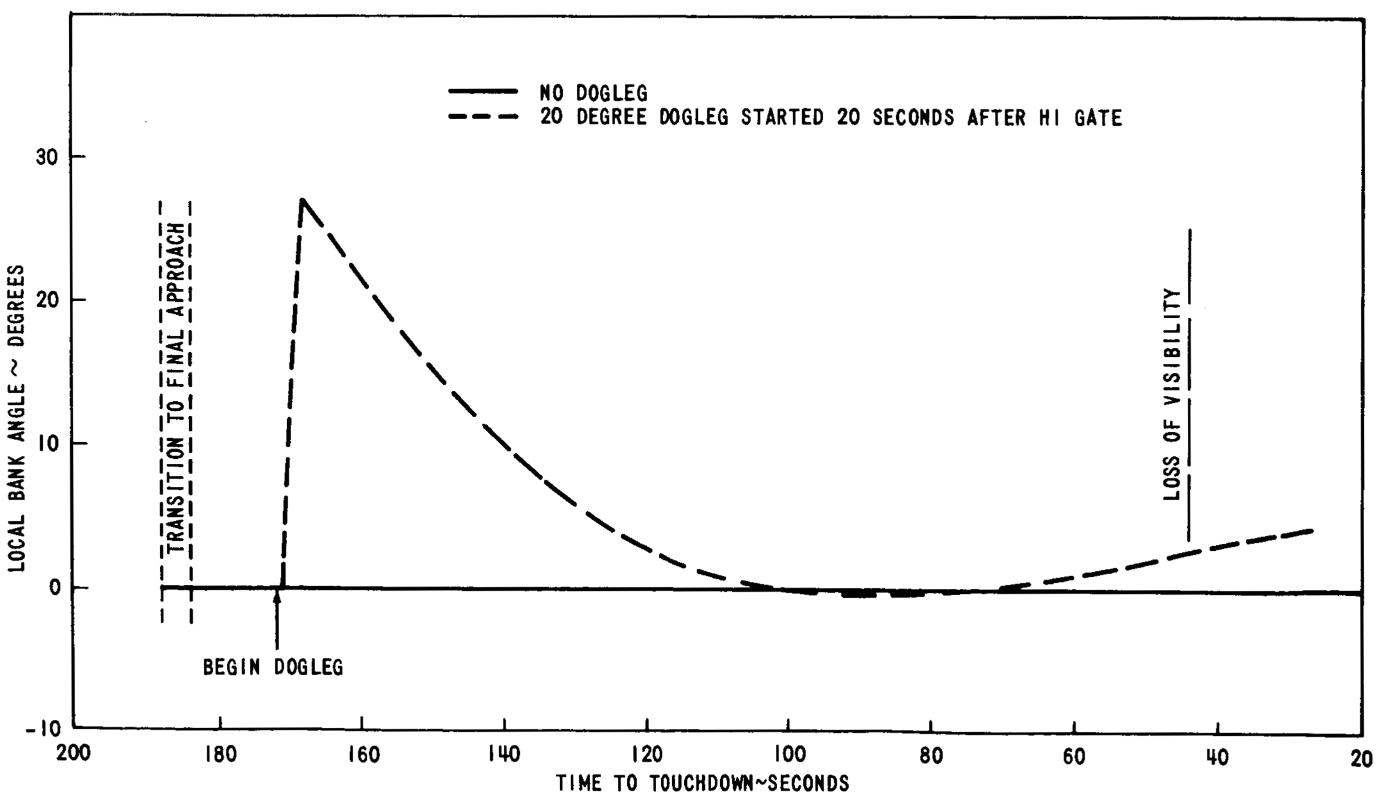


f) LOOK AZIMUTH ANGLE

FIGURE 4 - COMPARISON OF DOGLEG AND NO DOGLEG APPROACHES (CONT.)

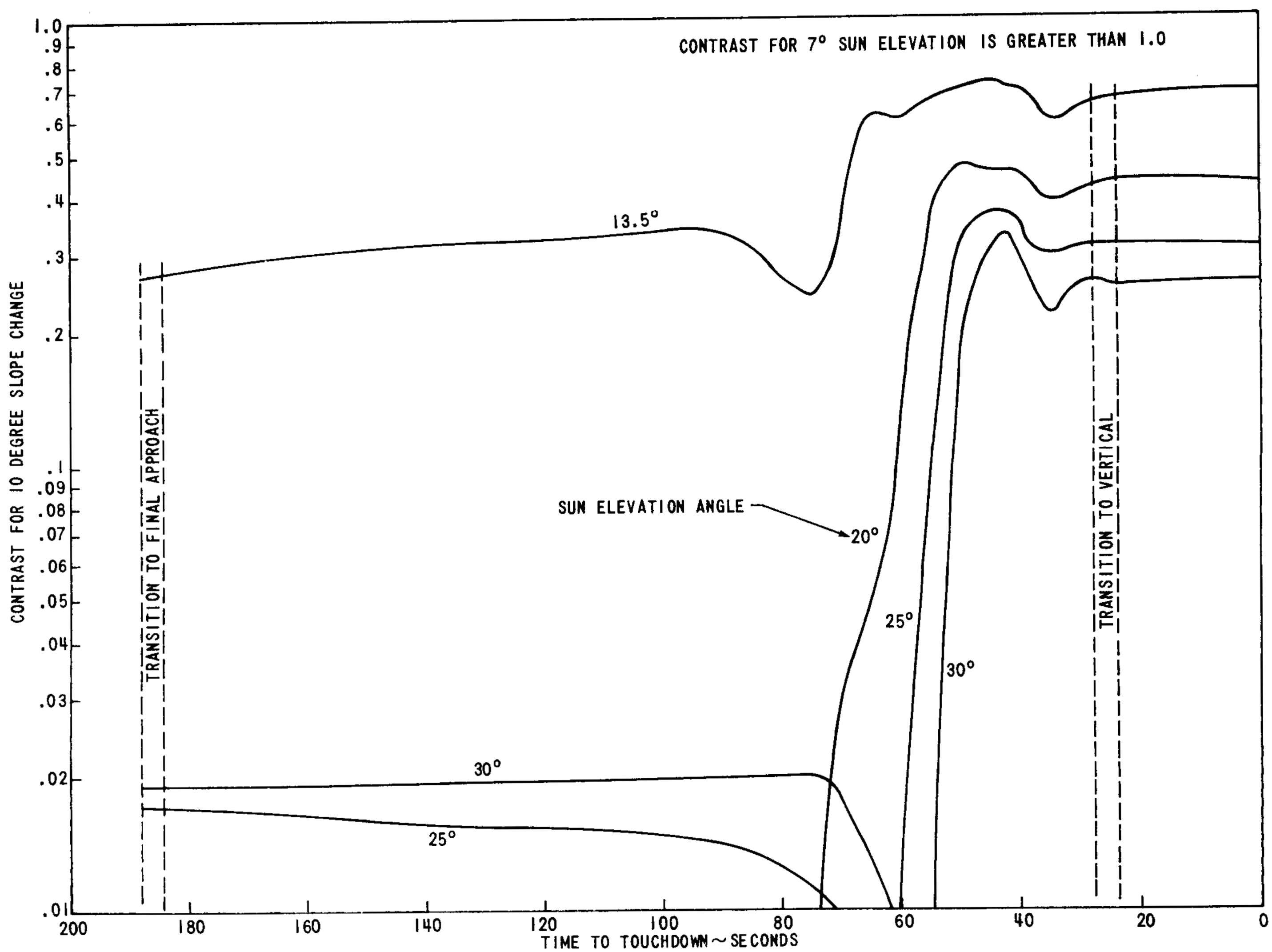


g) LOCAL PITCH ANGLE



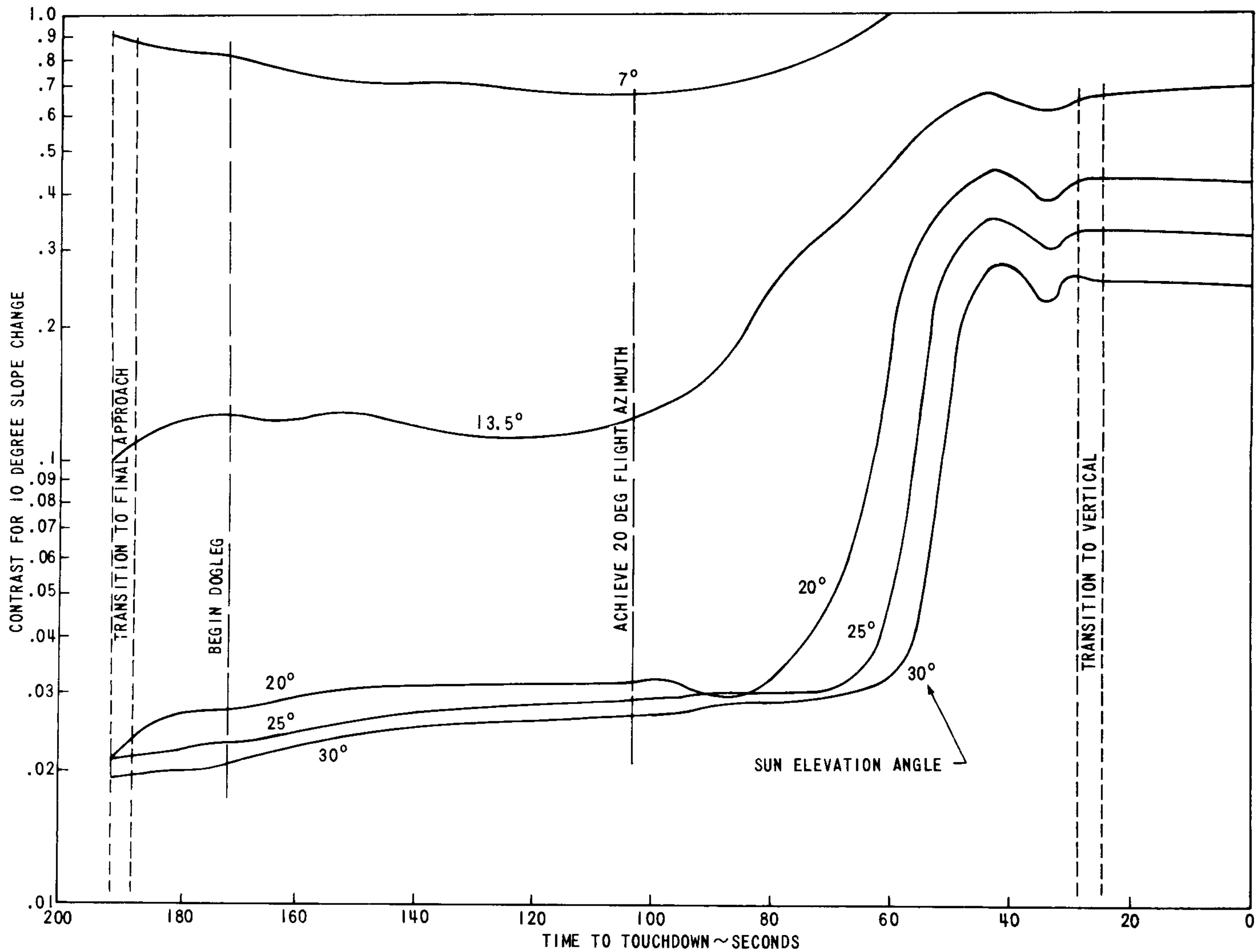
h) LOCAL BANK ANGLE

FIGURE 4 - COMPARISON OF DOGLEG AND NO DOGLEG APPROACHES (CONT.)



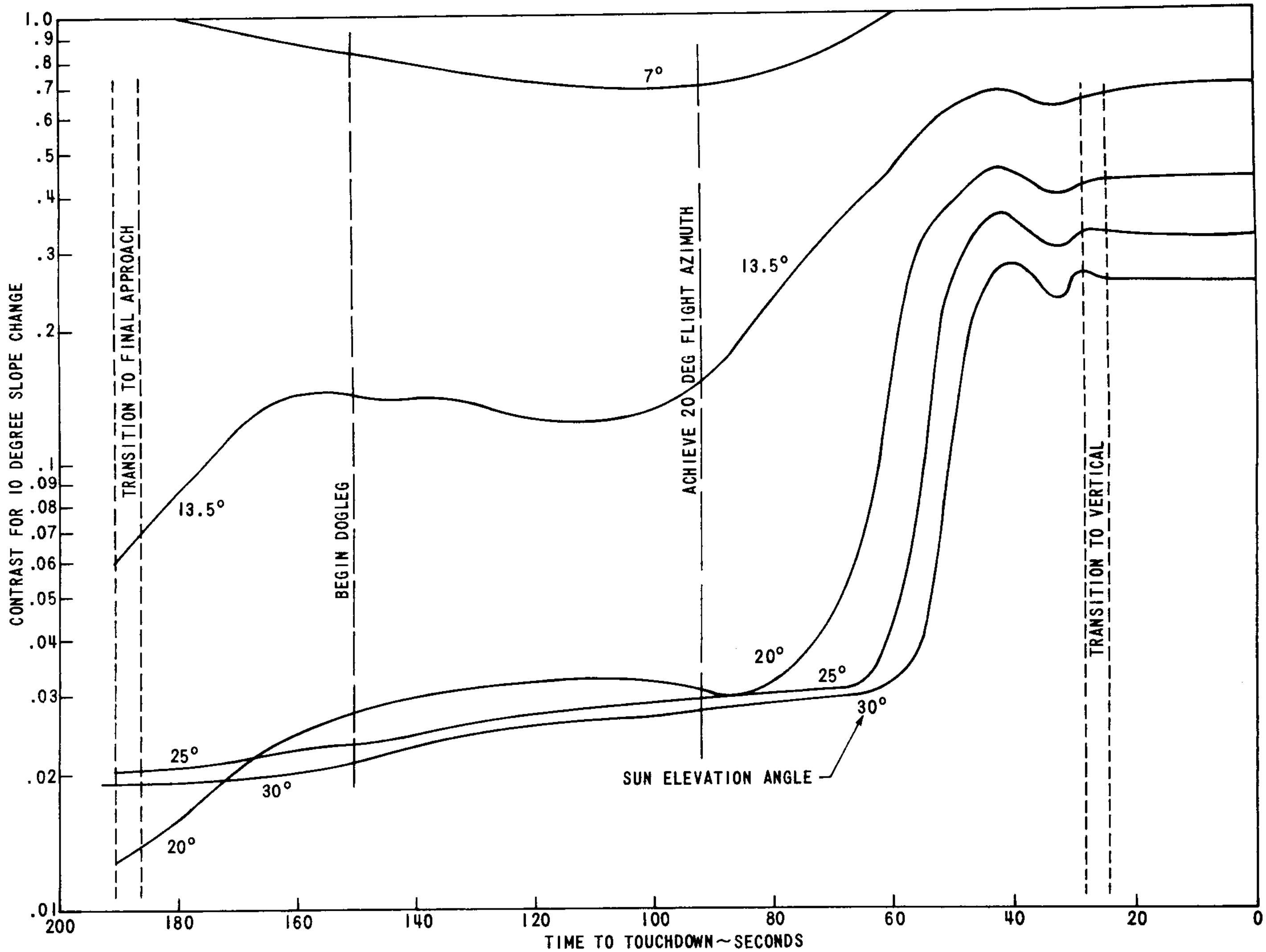
a) NO DOGLEG

FIGURE 5 - CONTRAST HISTORY DURING LM DESCENT



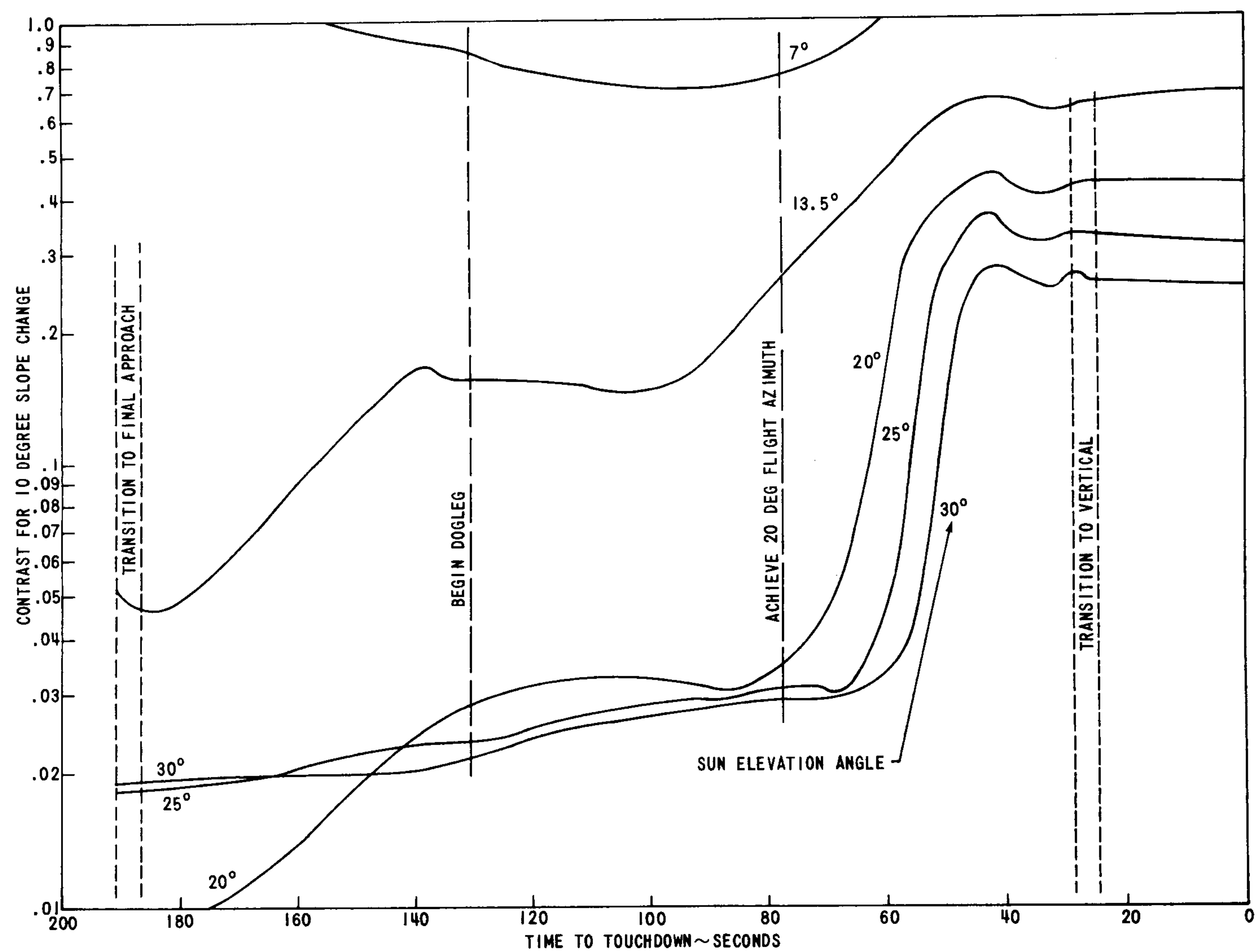
b) DOGLEG OF 20 DEGREES STARTED
20 SECONDS AFTER HI GATE

FIGURE 5 - CONTRAST HISTORY DURING LM DESCENT (CONT.)



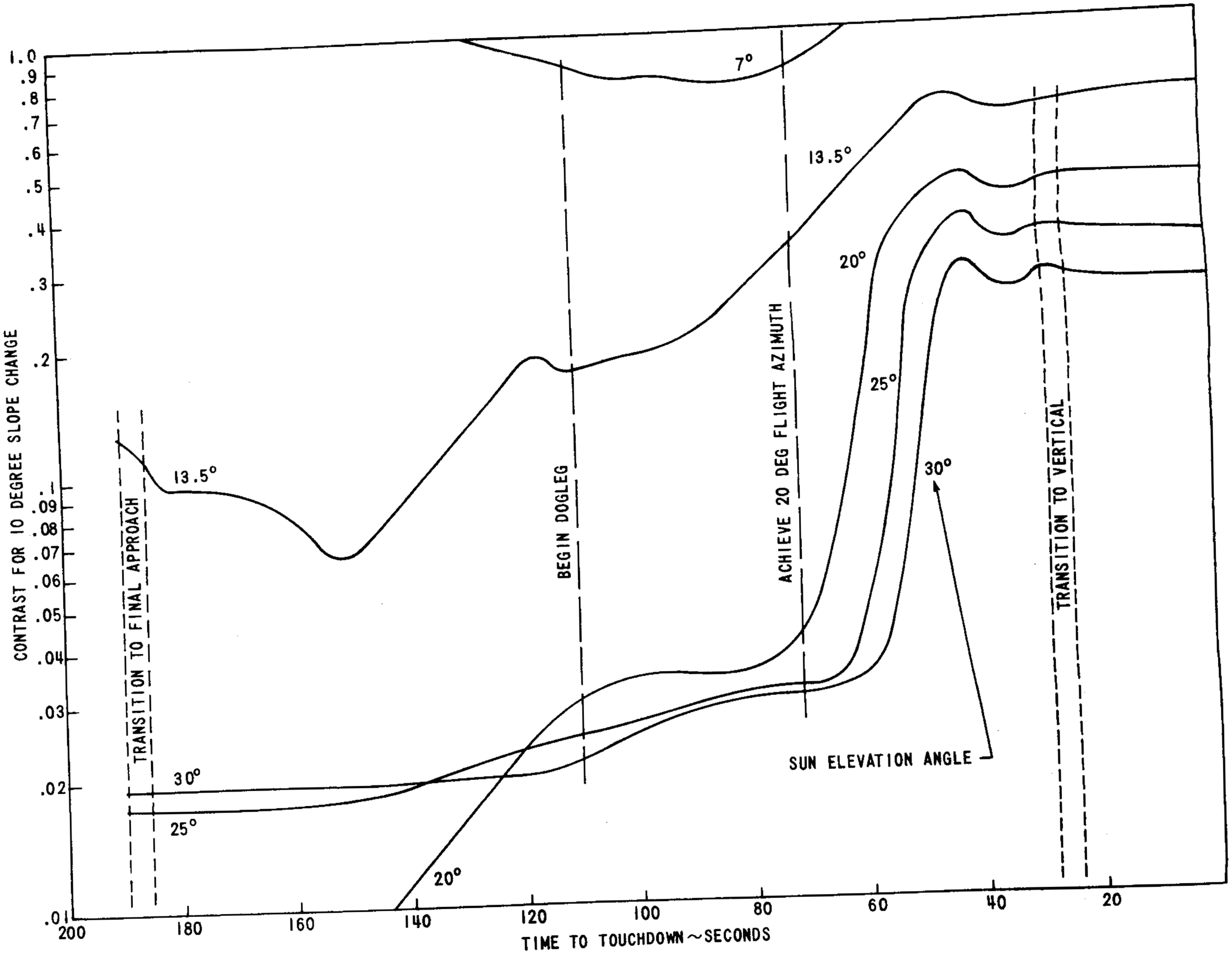
c) DOGLEG OF 20 DEGREES STARTED
40 SECONDS AFTER HI GATE

FIGURE 5 - CONTRAST HISTORY DURING LM DESCENT (CONT.)



d) DOGLEG OF 20 DEGREES STARTED 60 SECONDS AFTER HI GATE

FIGURE 5 -- CONTRAST HISTORY DURING LM DESCENT (CONT.)



e) DOGLEG OF 20 DEGREES STARTED
80 SECONDS AFTER HI GATE

FIGURE 5 - CONTRAST HISTORY DURING LM DESCENT (CONT.)

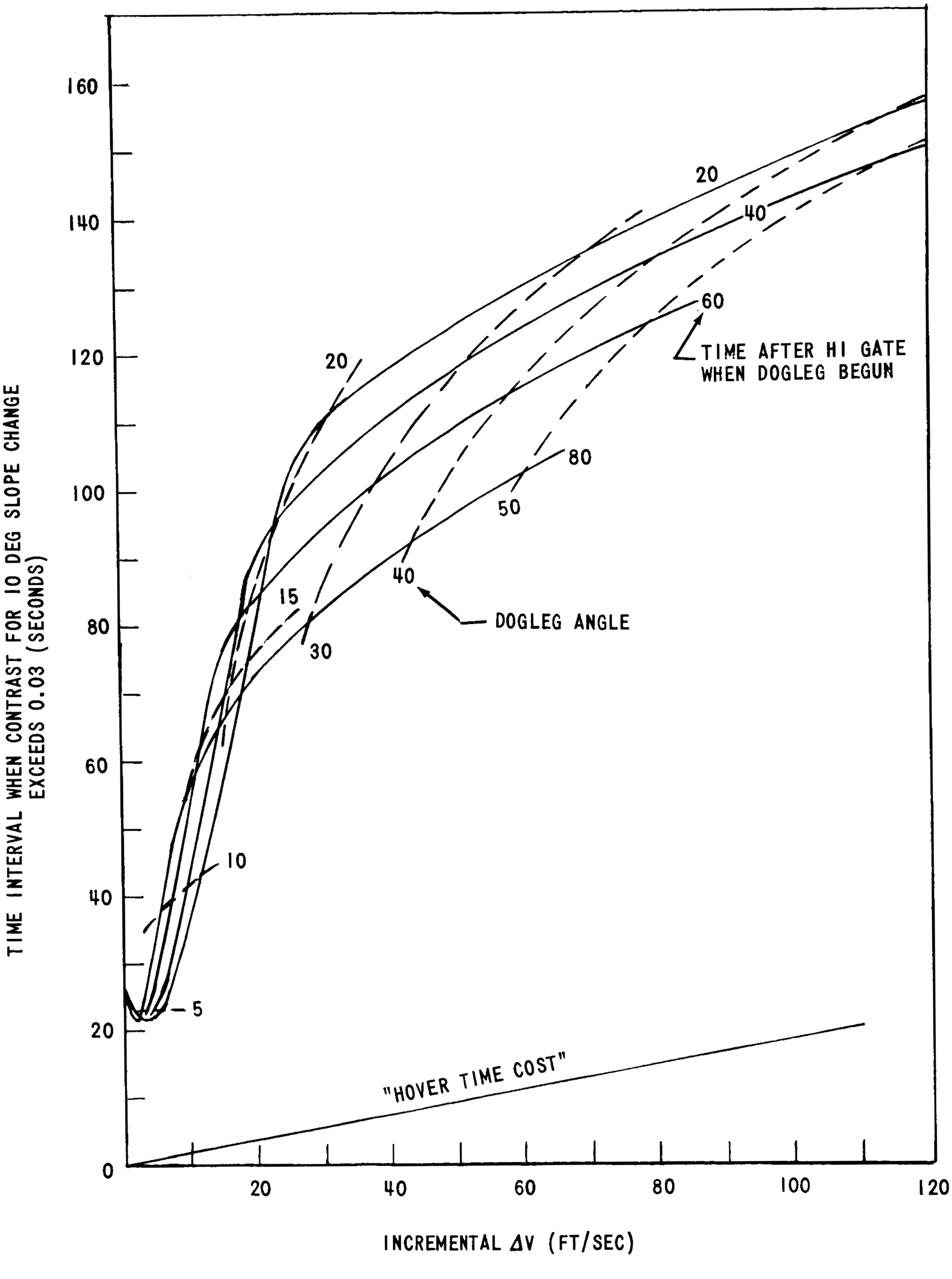


FIGURE 6 - COST OF INCREASED CONTRAST IN DOGLEG - SUN ANGLE 20 DEGREES

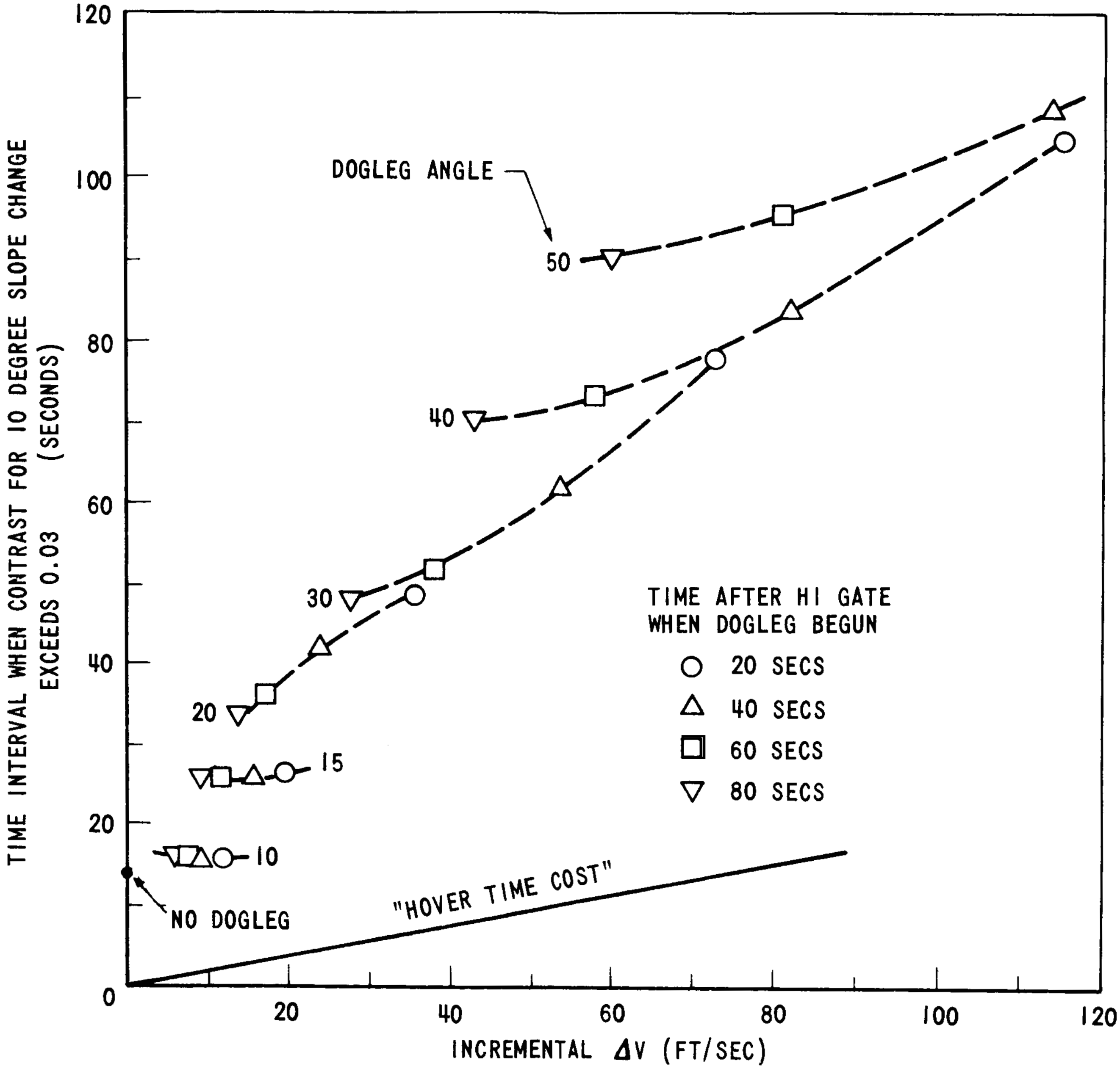


FIGURE 7 - COST OF INCREASED CONTRAST IN DOGLEG - SUN ANGLE 25 DEGREES

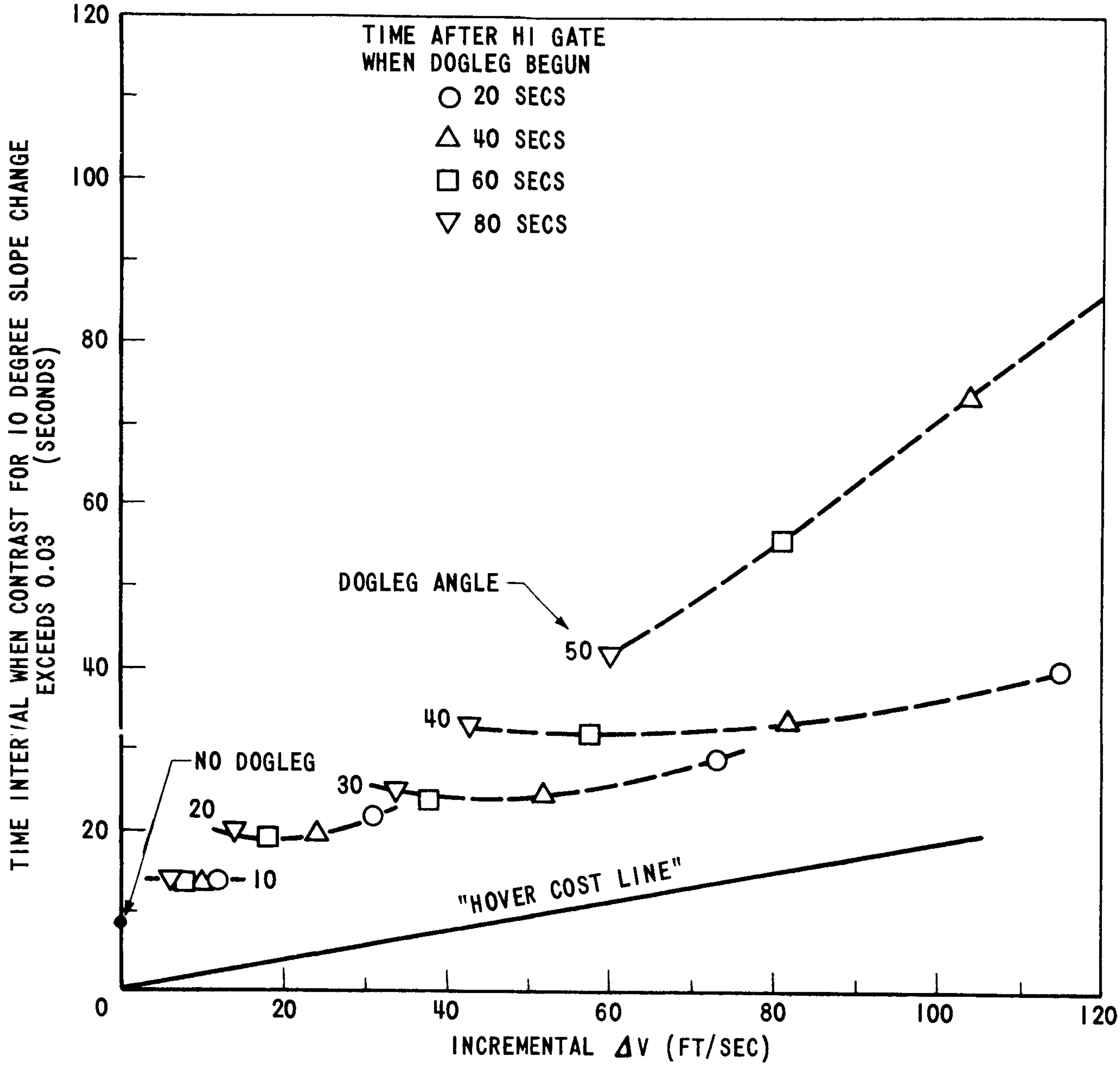


FIGURE 8 - COST OF INCREASED CONTRAST IN DOGLEG - SUN ANGLE 30 DEGREES

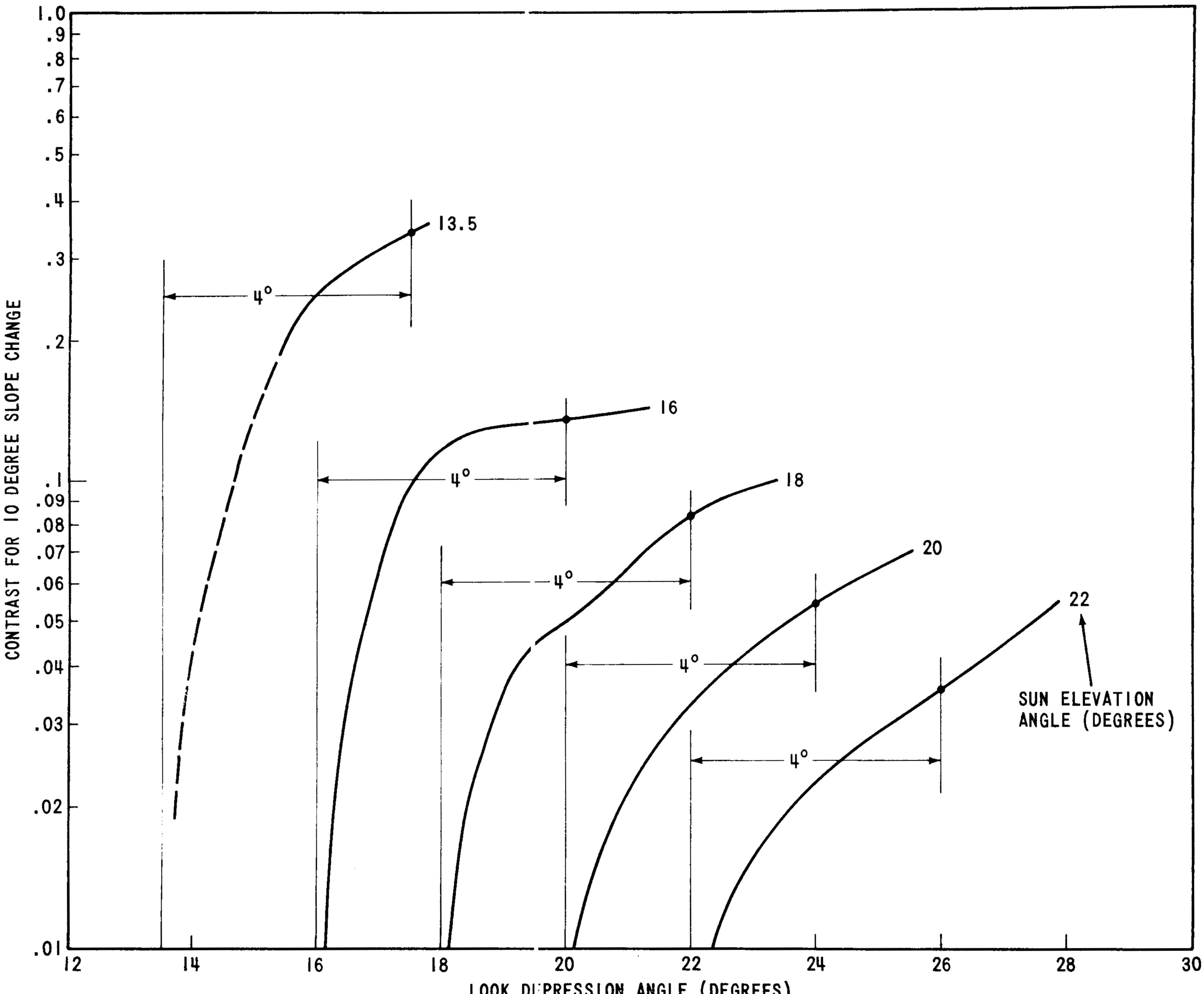


FIGURE 9 - NO DOGLEG